

Chapter 20

Quality Assurance

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20.1 Introduction

Treatment planning systems are computer software trying to predict the real dose absorbed by the patient using experimental data. Technologic progress in recent years has made it possible to obtain planning techniques for high-dose gradients by using inverse planning techniques. Obtained doses from three dimensional conformal radiotherapy (3D-CRT) can be validated by calculation of doses at different points. However, more knowledge and skill are expected from intensity modulated radiotherapy (IMRT) planning systems. Unlike the 3D-CRT, the IMRT field is made of many small, asymmetrical and irregular subfields. Subfields correctively obtained as a result of leaf positions are more important than in 3D-CRT. As subfields are created with multileaf collimators, naturally, accuracy of the multileaf collimator becomes more important. Multileaf collimator positioning error in IMRT causes worse results than in 3D-CRT. Furthermore, leaf transmission, output linearity, and similar data affect IMRT results much more than 3D-CRT results. Therefore, medical physicists must check the reality of results predicted by the planning system and each clinic must have its own specific quality assurance (QA) procedure [1].

20.2 Quality Assurance in Breast IMRT

The difference between the radiated and planned dose is obtained from QA programs. QA consists of clusters that overlap or intersect under hierarchy. Practical application of QA built over correct logical elements provides both reliable treatment opportunity

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Table 20.1 Summary of recommendations for linear accelerators in the AAPMTG 142 Report

Dosimetry	Limit	Frequency
X-ray output constancy	3%	Daily
X-ray output constancy	2%	Monthly
X-ray output calibration	1%	Annually
Dose rate output constancy	2%	Monthly
Photon beam profile constancy	1%	Monthly
X-ray flatness and symmetry change from baseline	1%	Annually
X-ray beam quality	± 1 from baseline	Annually
X-ray monitor unit linearity	$\pm 5\%$ (2–4 MU), $\pm 2\%$ ≥ 5 MU	Annually
X-ray output constancy vs. dose rate	$\pm 2\%$ from baseline	Annually
X-ray output constancy vs. gantry angle	$\pm 1\%$ from baseline	Annually
Laser localization	1.5 mm	Daily
Distance indicator at isocenter	2 mm	Daily
Collimator size indicator	2 mm	Daily
Light/radiation field coincidence	2 mm or 1% on a side	Monthly
Light/radiation field coincidence (asymmetric)	1 mm or 1% on a side	Monthly
Gantry/collimator angle indicators	1^0	Monthly
Gantry/collimator/couch rotation isocenter	± 1 mm from baseline	Annually
Jaw position indicator (symmetric)	2 mm	Monthly
Jaw position indicator (asymmetric)	1 mm	Monthly
Cross-hair centering (walkout)	1 mm	Monthly
Treatment couch position indicators	2 mm/ 1.0^0	Monthly
Localizing lasers	1 mm	Monthly

and a saving of time. In general, QA can be examined under two topics. The first of these is machine QA and the other is patient-specific QA. Performing machine QA by a physicist on a routine basis directly affects the results of patient-specific QA within tolerance limits. Thus, errors in patient-specific QA can be reduced to a minimum. Because of this perspective, QA approaches in breast IMRT will be from general to specific. The concept of QA in breast IMRT is the application of patient-specific QA of a patient in the third even fourth degree for a specific region. Dose accuracy detection with QA at the end of the breast IMRT requires more than just two-dimensional (2D) and three-dimensional (3D) dose analysis. For the correct IMRT QA, an optimal device QA and treatment planning system should be made. In this way, defects in breast IMRT QA can be reduced to the lowest level and reasons can be understandable. In the case of a misplaced leaf, QA cannot be expected to give good results in a linear accelerator. However, if a clinic does not check the accuracy of leaf movements, errors can occur making precise predictions difficult [2–7].

The lineal accelerator (LINAC), which will be used for IMRT applications must have the essential sensitivity. The basis for this sensitivity includes QA programs, output, field size, gantry angle, collimator angle, gantry rotation axis stability, and leaf position controls and these must be kept within specified limits for IMRT that are provided by the international organization AAPM TG and ESTRO. Tables 20.1 and 20.2 are the summaries of LINAC and MLC QA which are adapted from the American Association of Physicists in Medicine Task Group (AAPM TG) 142 report [7].

Table 20.2 A summary of recommendations for multileaf collimator in the AAPMTG 142 Report

MLC	Tolerance	Frequency
Quantitative test (matched segments, picket fence)	Visual inspection	Weekly
Travel speed	Loss of leaf speed >0.5 cm/s	Monthly
Leaf position accuracy	1 mm	Monthly
MLC transmission	±0.5% from baseline	Annually
Leaf position repeatability	±1.0 mm	Annually
MLC spoke shot	≤1.0 mm radius	Annually
Coincidence of light field and X-ray field	±2.0 mm	Annually
Segmental IMRT test	<0.35 cm max. Error Root Mean Square (RMS), 95% of error counts <0.35 cm	Annually
Moving window IMRT	<0.35 cm max. Error RMS, 95% of error counts <0.35 cm	Annually

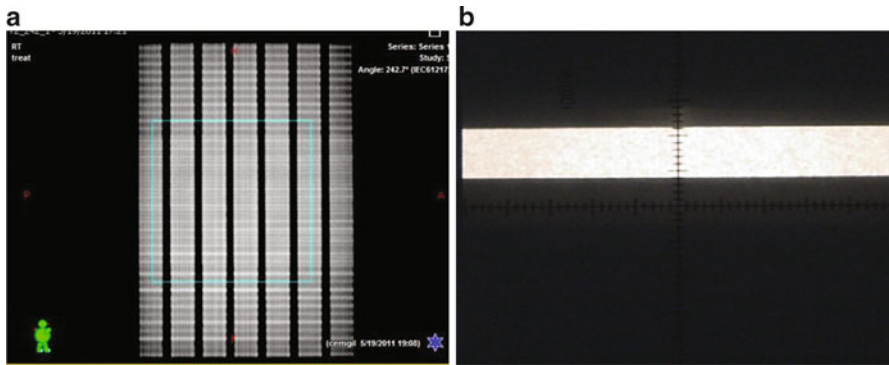


Fig. 20.1 a Picket fence test. b A frame from multileaf collimator motion video

The most popular Multi Leaf Collimator (MLC) positioning test is the “picket fence.” The purpose of this test is to inspect leaf position according to the other leaves as shown in Figure 20.1a. The picket fence test has some variations. An alternative method to investigate MLC position and speed can be detected by using a commercial video camera. Motion of MLC can be recorded on film and can be investigated with various programs. As frames of video are a time indicator, it is possible to measure the speed of the MLC leaf and compare the position of each leaf according to the others [8–12].

If these basic requirements are provided, the causes of errors in QA can be understood better. Then, the treatment planning systems are programs that predict dose accurately under predefined conditions.

20.3 Patient-Specific Quality Assurance in Breast IMRT

Considering the anatomic structure and radiation interactions, the breast cannot be easily fixable in its placement with a target volume in the build-up zone and having neighboring organs such as the lungs and heart with different densities. Therefore, QA must consider these features.

20.3.1 Ion Chamber-Based Quality Assurance Methods

The basic approach in a patient-specific QA procedure in IMRT is to measure the absorbed dose using an ion chamber. As a result of the achievability and the availability of the equipment, this is the basic QA method. It is possible QA with an ion chamber and slab water equivalent phantom in the absence of special QA phantoms designed for IMRT. QA with large volume ion chamber and slab phantom requires more effort and attention regardless to QA by using phantoms which are specifically developed for IMRT. Even after these efforts, results may not be satisfactory, thus, the usability of this approach is limited. IMRT is a treatment with steep dose gradients. Detectors, which have high spatial resolution, are required in these steep dose gradient regions. Because of this requirement, an ion chamber with a small radius to a smaller active volume is needed. Ion chambers used in absolute dosimetry must be able to make correct readings even at the smallest subfield. On the other hand, decrease in volume will result with loss in dose response and make the signal-to-noise ratio an issue.

Measurements in high dose gradient regions as shown in Figure 20.2 will probably result with unexpected differences between planned and measured doses. This situation inserts another uncertain factor into the QA mechanism. In the case of a fail in QA, this uncertainty causes difficulties in the prediction of the error. Furthermore, errors resulting from the inability of the detector in steep dose gradient regions might be regarded as inability of the treatment planning system.

The workflow in an ion chamber-based QA is as follows:

1. Make a combination of phantom
 - a. Do not place the ion chamber in the buildup region
 - b. Put sufficient phantom between detector and coach for back scattering
 - c. Put phantom combination to CT coach properly for taking scan
2. Obtain CT scan of the phantom
 - a. Put marker on the phantom according to lasers or, if they already exist, arrange phantom according to lasers
 - b. To avoid the artifacts during CT scan do not place detector in phantom
 - c. Leave detector hole empty or use proper sticks

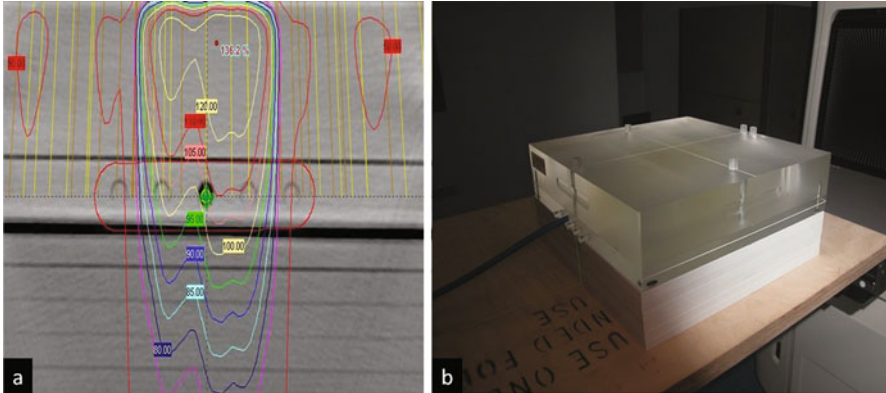


Fig. 20.2 **a** An ion chamber in high dose gradient region. **b** An ion chamber and a special phantom for IMRT QA

3. Transfer CT data to treatment planning system

- a. Create the plan
- b. Define planning target volume (PTV) at the active volume of the detector
- c. If the hole is empty set the PTV HU to zero
- d. Transfer IMRT plan to phantom, set the gantry and the collimator angles to zero
- e. Check the detectors to see if they are in high dose gradient region or low dose region
- f. Control the dose change in PTV volume
- g. Find the mean PTV dose

4. Irradiate the phantom

- a. Set the phantom in LINAC according to step 2a
- b. Check the laser and other equipment (i.e., Source Skin Distance (SSD), etc.)
- c. Put the detector into the hole and repeat step 4 at least two times for different points.

The number of measurements increases the reliability of PLAN but decreases the applicability of QA program, if there exists only one detector and a single-channel electrometer in the clinic. The difference between expected and measured dose must be within 3%.

A high dose gradient is observed and expected near the heart and lung. The breast is usually irradiated in tangential form and treatment planning algorithms include corrections for tangential irradiation. On the other hand, when suggested irradiation conditions are taken into account, the detector is beyond the build-up region because the gantry angle is at zero degrees and the field is orthogonal to the surface of the phantom, dose calculation for QA is not tangential. The irradiated structure is a semiinfinite medium instead of a body with different densities, concavities, and convex. These difficulties must be taken into account in clinical practice. Cylindrical phantoms may be used for testing tangential irradiation performance and inhomogeneity phantoms may be used for inhomogeneity correction performance of algorithms [4, 13].

20.3.2 Two-Dimensional Measurement Systems

Development in IMRT is accompanied by development in dosimetric systems. Currently, gamma analysis and distance to agreement methods are the most widely used methods for determining the accuracy of dose distribution obtained from the treatment planning system. These are the 2D analysis methods that examine the relationship between dose and ranges. It is very difficult to perform these two analysis methods with a single ionization chamber and solid phantom assembly. To use these analysis methods, 2D measurement systems are needed. Two-dimensional measurement systems can be grouped under three main topics: 2D diode or ion chambers, the use of electronic portal imaging devices (EPID) as a detector, and films. A 2D ionization chamber and diode detectors consist of many detectors which are placed on a matrix with a certain number of intervals. The measurement software offers different analysis opportunities to the user. Portal imaging devices act similarly to the dosimetry equipment, and they are part of the LINACs. Portal imaging devices in LINACs with software support become effectively used in QA for a dosimetric system in IMRT. Another type of 2D dose measurement system is film. As mentioned before, 2D ion chambers are made by detectors placed on a matrix at certain intervals. This structure brings the concept of a resolution of 2D detectors. Dose behavior is considered linear between two detectors. Also, a similar situation exists in portal dosimetry devices because they have certain resolutions. However, the film differs from the detectors with granular structure and almost has an infinite resolution. Depending on the developments in radiochromic film technology, and with the contribution of homemade dosimetry measuring, the popularity of films has increased. A variety of commercial software for analysis, as well as some scientific software used in analysis with film, has attracted the attention of curious users.

20.3.3 Two-Dimensional Detectors

As in the IMRT QA with an ion chamber, some 2D detectors combine solid phantoms. A combination of detector and phantom is illustrated in Figure 20.3. The QA flow chart for 2D detectors is similar to the ionization chambers, and the only difference is that the dose map plane is examined instead of the mean dose value. The combination of phantom and detector are reestablished in LINAC and then irradiated. As a result of irradiation, a dose map is composed in the detector plane. Exported dose maps from treatment planning systems are compared with the obtained dose maps after irradiation using the appropriate software. As a result of comparison, gamma analysis and/or distance to agreement value is examined.

Some 2D measurement systems do not require the use of CT and can be used in combination with phantoms as in other systems. The plan is transferred onto a virtual water phantom and the dose plane at the depth projectile in the detector's active plane is then exported for examination. Similarly to other detectors, the



Fig. 20.3 Combination of array and phantom

irradiated plane must have the same depth as the exported plane. With or without the need of CT, these detectors can be mounted to gantry heads as shown in Figure 20.4.

20.3.4 Quality Assurance With the Electronic Portal Imaging Device

Another effective measurement system for QA is an EPID mounted on LINAC. The use of EPID for relative dosimetry reduces the time spent on QA for IMRT. With an effective database management, acquired images can be directly compared with the data obtained from the treatment planning system and patient-specific data can also be saved for future use. EPID in IMRT QA methods is quite common and it is possible to perform analyses as in the other 2D QA methods, and gamma and distance to agreement analysis are possible with EPID electronic portal dosimeter (Figs. 20.5 and 20.6).

20.3.5 Quality Assurance With Films and Miscellaneous Systems

There are different types of radiation detection systems for IMRT QA, such as radiographic film, radiochromic film, thermoluminescence dosimetry (TLD), different types phantoms, gel dosimetry, or other types of 3D dosimetric systems.



Fig. 20.4 Gantry mounted array

Films and TLDs are the most common miscellaneous measurement systems in radiotherapy. Both film and TLD chips can be used as planar 2D detectors with suitable phantoms. Like other 2D detectors for gamma analysis, distance to agreement analysis with films is also possible. Irradiated film is scanned with a suitable scanner, and with this process it becomes digital. Digitalized film can be analyzed with a commercial film analysis program or scientific software.

Films can be used in vivo dosimeter as TLD chips. In breast treatment, the target is close to the skin and it is hard to mobilize the breast. This situation raises the question whether the part of the target close to the skin is irradiated properly or not. Obtaining a good plan using a flash region in IMRT plan is suggested in ICRU 83 for adequate irradiation. Also, films can be used to validate repeatability of the treatment. It is also possible to check dose of incision scar.

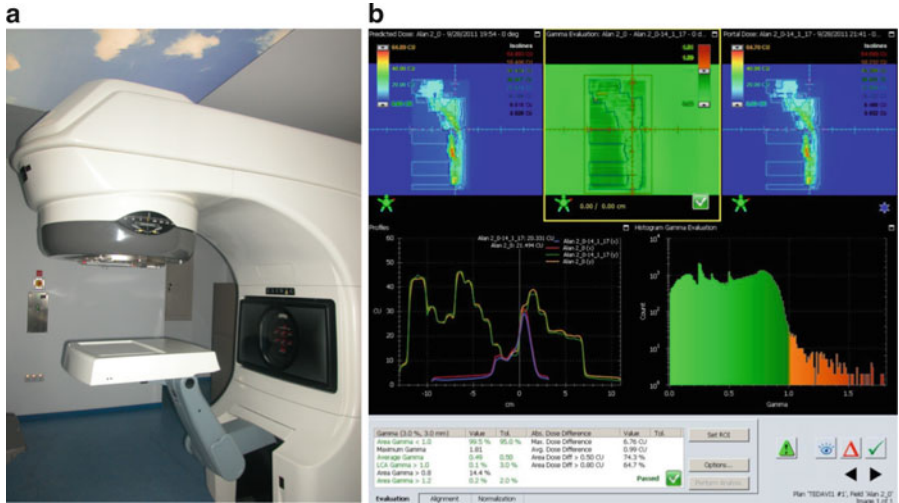


Fig. 20.5 a Electronic portal imaging device (EPID); b a sample of EPID dosimetry

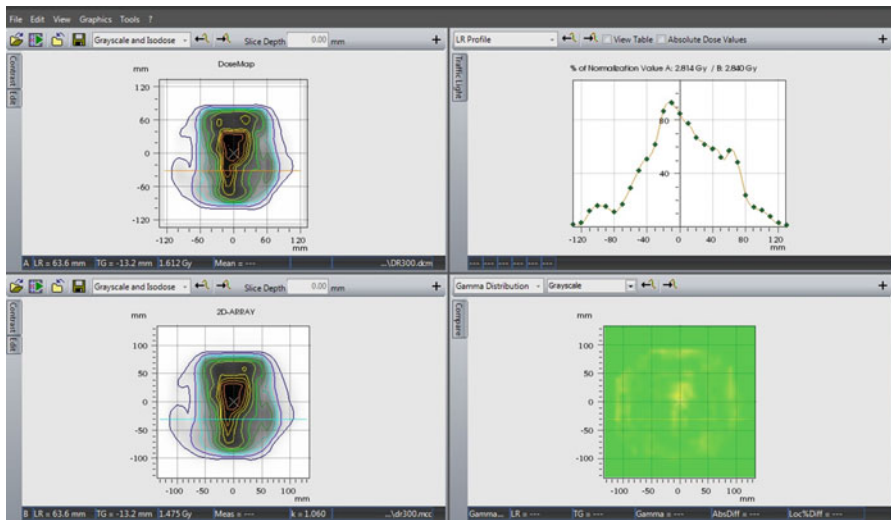


Fig. 20.6 A screen shot of gamma analysis report of a 2D array

20.4 Evaluation of Two-Dimensional Dosimetry Analyses

Distances to agreement and gamma analysis are the most common quantitative dose map comparison methods.

20.4.1 Distance to Agreement

(x_r, y_r) is the point on the measurement plane, where dose D_r is read. If dose D_c at (x_c, y_c) , which is corresponding to the point (x_r, y_r) , on calculated dose is in the acceptable interval $d\%$, then point is said to be acceptable. If D_c is not in the interval, then the algorithm seeks to find a point (x_{1c}, y_{1c}) , where dose is equal to D_r , in the radius as defined as distance to agreement. So, if the user sets the distance to agreement value to 3 mm, the system tries to find a point with dose D_r in this radius. If there are two points with a dose higher than D_r and less than D_r in this circle, then it is said that there is at least one point with dose D_r in this circle [14, 15].

20.4.2 Gamma Analysis

(x_r, y_r) is the dose measurement point and $\gamma(x_r, y_r)$ is the gamma value of this point in the reference image. This value is

$$\gamma(x_r, y_r) = \min_{x_c/y_c} \{\Gamma_r(x_c, y_c, D_c)\} \quad (1)$$

where $\Gamma_r(x_c, y_c, D_c)$ is gamma value of point x_c, y_c on the calculated image according to point x_r, y_r on the reference image and equal to

$$\Gamma_r(x_c, y_c, D_c) = \sqrt{\frac{\Delta r^2}{\Delta d_{max}^2} + \frac{\Delta D^2}{\Delta D_{max}^2}} \quad (2)$$

where Δr is the distance between two reference points

$$\Delta r = |\vec{r}_c - \vec{r}_r| = (x_c - x_r)^2 + (y_c - y_r)^2 \quad (3)$$

and ΔD is the dose difference between two points

$$\Delta D = D_c(\vec{r}_c) - D_r(\vec{r}_r) \quad (4)$$

$r_r = (x_r, y_r)$ is the position in the reference dose distribution, $r_c = (x_c, y_c)$ is the position in the calculated dose distribution, ΔD_{max} is the dose tolerance (i.e., 3%), Δd_{max} is the space tolerance (i.e., 3 mm).

If (x_r, y_r) value is less than or equal to 1, then the point (x_r, y_r) is accepted as a passed point. If the ratio of the total number of passed point ratios to total number point is greater than 95%, then analysis is accepted as passed [3, 15].

The passing rate of the analysis is expected to be 100% in ideal cases, but in practice this may not be achieved. Medical physicists must investigate failed points. After analysis, the points that cannot pass must be searched and compatibility must

be checked because this point can occur in the lung, heart, or anywhere in the body except the critical organs. Analysis results should be evaluated clinically.

If an error is observed at the edge of the collimators which are parallel to the MLC motion direction, the error is usually caused by modeling of field size in the treatment planning system. During treatment, some leaves stay in the field without moving for a long time in respect to the beam time. In such cases, if the leaf transmission value is defined improperly in the treatment planning system, failed points are observed in low dose regions. This failure is an indicator of wrong leaf transmission value insertion.

20.5 Conclusion

Heartbreaking results of IMRT applications in the news prove the importance of QA. Obviously, there is no perfect system and for this reason, the desired treatment may not be given. Quality control is in effect from the beginning of system installation to the end of patient treatment. Measurements regarding LINAC should be made correctly and must be installed correctly in the treatment planning system. As in every process, this process must also be checked. The QA program for the LINAC should be applied in a sustainable way. After the approval of device suitability, it is still important to perform QA to avoid the errors that may occur. QA for patients gives feedback about the status of the system at the same. Different software can offer more than one analysis method, and the job of a medical physicist is not to search for the analysis methods where a plan exists, but to examine the analysis methods that fail.

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